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Ecological Forecasting Project on

Ecological Condition of US National Parks: Enhancing Decision Support Through Monitoring, Analysis, and Forecasting

Also called:

Park Analysis of Landscapes and Monitoring Support (PALMS)

Final Report

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Executive Summary

The purpose of this document is to report accomplishments of the NASA DECISION-funded project, "*Ecological Condition of US National Parks: Enhancing Decision Support Through Monitoring, Analysis, and Forecasting*". This project provided the U.S. National Park Service (NPS) with enhanced and new capabilities to use and integrate NASA data and products into the NPS Inventory and Monitoring (I&M) Program decision support tools (DSTs).

The need for monitoring and decision support for US National Parks is heightened by the rapid change that is occurring in and around parks. To address this need, National Park Service (NPS) has developed the Inventory and Monitoring (I&M) Program to provide a framework for collecting and archiving data pertaining to park vital signs including physical, chemical, and biological elements of ecosystem processes within parks. At the time of initiation of this project, however, the NPS I&M made only limited use of remotely sensed data and ecosystem models to simulate and forecasts ecosystem conditions.

The goal of this project is to integrate the routine acquisition and analysis of NASA Earth System Science products and other data sources into the NPS I&M DSTs and use these NASA products to evaluate and forecast ecological condition of US National Parks, thereby enhancing natural resource management within and surrounding national parks. Specific objectives of this project are:

1. (a) Identify NASA and other products useful as indicators for NPS I&M monitoring and (b) delineate the boundaries of the surrounding park-centered ecosystems (PCE) appropriate for monitoring.
2. Add value to these data sets for understanding change through analysis and forecasting.
3. Deliver these products and a means to integrate them into the NPS I&M decision support framework.

The project focuses on four sets of national parks to develop and demonstrate the approach: Sequoia Kings Canyon and Yosemite National Parks, Yellowstone and Grand Teton National Parks, Rocky Mountain National Park, and Delaware Watergap National Recreation Area and Upper Delaware Scenic and Recreational River.

This report summarizes progress to date, overviews related projects, and evaluates progress based on responses to a questionnaire by our NPS I&M cooperators.

This report provides background on the project and a description of the DST, describes the enhancements completed through this project, and assesses the effectiveness of the project from the perspective of the Principle Investigators and the NPS collaborators. This assessment is based largely on comparison of responses to a comprehensive questionnaire completed by the cooperators in the second year of the project and again at the conclusion of the project. We conclude with recommendations for future collaborations between NASA and the NPS.

We first identified a set of indicators of park condition and health that could be generated from NASA and related data and models and that were high priorities for each of the four collaborating NPS I&M Networks (Obj 1a). This was done via workshops with each of the four networks during 2008. Among the 16 indicators selected are those dealing with weather and climate, hydrology, land cover and use, disturbance, primary production, and biodiversity. An objective method for delineating the boundaries of park-centered ecosystems based on five ecological criteria was developed and applied to parks in the four case study networks and two additional ones (Obj 1b). This was done to allow monitoring to be focused on the areas most relevant to the ecological condition of the parks. Data sets, hindcasts and forecasts, analyses, and maps have been prepared for the indicators (Obj 2). These products and methods for repeating them were delivered to the NPS (Obj 3) via a geodatabase, methods manuals in the format of NPS I&M Standard Operating procedures (SOPs); summary reports, a dedicated internet site and the internet-based interface Ecocast. Specific contributions of the project include:

- Delivery of some 16 indicators of landscape condition that are relevant and novel to the NPS I&M Program and to the case study national parks.

- Written methodologies for producing the indicators in the form of NPS Standard Operating Procedures and background peer-reviewed publications.
- Written summaries of the major trends in landscape condition of the case study parks and implications for management.
- Methods for delineating the lands surrounding national parks that are most relevant to maintaining park condition under land use change as a basis for monitoring, research, and collaborative management.
- Hindcasts and forecasts of park condition that provide a unique temporal context to inform management decision making.
- Means by which the NPS can obtain data on the lands surrounding parks that cannot be obtained by traditional field methods due to ownership and privacy issues.
- Exposure of NPS collaborators to new capabilities for environmental monitoring, analysis, and modeling using NASA Earth Science research results that can help to manage and protect parks better.
- An approach for hindcasting, forecasting, analyzing, and delivering to users complex indicators of landscape condition that can serve as a model for other applications.
- Resource briefs on major trends in park condition that the NPS can use to communicate with stakeholders and the public.

The primary means of assessing progress at this point in the project was a questionnaire completed by personnel from each collaborating NPS I&M network. The questions examined the relevance of the products, the adequacy of the methods, the utility of the draft SOPs, potential value to decision support, and level of satisfaction with the project.

The results indicated that the respondents had a high level of satisfaction with the project. The list of indicators was generally considered relevant, nonduplicative, and valuable for assessing park condition. The concept of delineating park-centered ecosystems was seen as an objective approach for determining the area to be monitored. The hindcasting and forecasting of indicators was considered a substantial step forward in providing a context for interpreting current conditions and trajectories of change. The means of incorporating products of the project into decision support (e.g., Ecocast, SOPs) were well received.

Expectations were less well met with regards to the goal of integrating our indicators into NPS I&M decision support and enhancing natural resource management within and surrounding national parks. The expectation that NPS I&M networks would fully incorporate production of our indicators into their monitoring protocols has largely not yet occurred. The translation of the results of the project to NPS decision makers has also been limited. Initial reception of our products by NPS has been positive, but the 3-year duration of the project is not long enough to accommodate the ongoing process of review, evaluation, understanding, and incorporation of the results.

We conclude that the project successfully accomplished the stated objectives. NASA data and products are considered highly relevant to the NPS I&M Program. Those relating to phenology of vegetation, ecosystem productivity, run-off, connectivity, and biodiversity are very informative for monitoring changes in park conditions under land use and climate change, and useful as a context for management. Our methods allowed these indicators to be collected not only inside of park boundaries, but also outside of parks where field collection is often difficult or impossible. The methods also allowed the NPS to track changes at spatial scales larger than parks, which are critical to maintaining ecological dynamics within parks. Interest in these indicators and methods will likely increase as the NPS develops and implements its climate change adaptation strategy.

Purpose of this Report

The purpose of this document is to report accomplishments of the NASA DECISION-funded project, "Ecological Condition of US National Parks: Enhancing Decision Support Through Monitoring, Analysis, and Forecasting". This project provided the U.S. National Park Service (NPS) with enhanced and new capabilities to use and integrate NASA data and products into the NPS Inventory and Monitoring (I&M) Program decision support tools (DSTs).

The Ecological Forecasting Program is an element of the Applied Sciences Program within the Earth Science Division of the NASA Science Mission Directorate. This program collaborates with partner organizations to extend the application of NASA's research results to policy and management DSTs. The purpose is to help these partner organizations expand their use of NASA earth science products, enhance their decision support capabilities, and increase the benefits to society derived from these products.

This "Final Assessment Report" is done following the "Ecological Forecasting Project Guidelines" of 18 December 2007. The report is based on Gross et al. (2011), which provided background on the project, overviewed the DST, described the enhancements done within this project, and assessed the effectiveness of the project from the perspective of the Principle Investigators. Herein, we add to Gross et al. (2011) an assessment of the impact of the enhancements to the NPS I&M DSTs from the perspectives of the NPS collaborators. This assessment is based largely on comparison of responses to a comprehensive questionnaire completed by the cooperators in the second year of the project and again at the conclusion of the project. We conclude with recommendations for future collaborations between NASA and the NPS. A listing of the products from the project and links to where they can be obtained is in Appendix I.

Background

U.S. National Park Service (NPS) units ("parks") are important components in a system of reserves that protect biodiversity and other natural and cultural resources. To meet the NPS mission to manage resources so they are left "…unimpaired for the enjoyment of future generations" it is essential to know what resources occur in parks and to monitor the status and trends in the condition of key resource indicators. The NPS Inventory and Monitoring Program (I&M; see Table 1 for a list of acronyms) was designed to provide the infrastructure and staff to identify critical environmental indicators ("vital signs") and to implement long-term monitoring of natural resources in more than 270 parks that contain significant natural resources (Fancy et al. 2009). The 270+ parks are organized into 32 ecoregional Networks (Figure 1). Each of the 32 I&M Networks consists of core professional staff (program manager, data manager, ecologists, field technicians, etc.), and each I&M Network supports monitoring in parks within the Network.

The overall purpose of I&M is to provide sound scientific information that enhances management of natural resources. To do so, I&M collects, organizes, and makes available natural resource data and contributes to the Service's knowledge by adding value to data though analysis, synthesis, and modeling. I&M initiated 12 basic natural resource inventories to collect the information needed as a foundation for monitoring, and to determine the current status of park resources (see Gross et al. 2011). Most inventories are now complete, except for the more expensive and time-consuming vegetation and geological resource inventories.

NPS I&M instituted systems-based "vital signs" monitoring to provide sound scientific information on trends in the condition of park natural resources. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Fancy et al. 2009). I&M Networks worked extensively with park personnel and other experts to identify the highest priority vital signs – a lengthy process that involved more than 1,000 people. Landscape dynamics, along with climate and invasive species, was ranked as one of the highest priorities for long-term monitoring across all the 32 I&M

Table 1. Acronyms used in this report.

Acronym	Meaning
AOA	Area of Analysis
DEWA	Delaware Water Gap Recreation Area
GIS	Geographical Information System
GPP	Gross Primary Productivity
I&M	U.S. National Park Service Inventory and Monitoring Program
LAI	Leaf Area Index
MODIS	Moderate Resolution Imaging Spectroradiometer
N	Naturalness
NARSEC	North American Network for Remote Sensing Park Ecological Condition
NASA	U.S. National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
nEPT	Number of *Ephemeroptera*, *Plecoptera*, and *Tricoptera* species
NPP	Net Primary Productivity
NPS	National Park Service
PACE	Protected Area Centered Ecosystem
PALMS	Park AnaLysis and Monitoring Support project
SOP	Standard Operating Procedure
TOPS	Terrestrial Observation and Prediction System
UPDE	Upper Delaware Scenic and Recreational River

Networks. Despite the high ratings, few I&M Networks have successfully developed landscape monitoring protocols and implemented landscape monitoring.

The slow development of landscape-scale monitoring reflects the complex decisions needed to identify a small set of indicators that are reasonably comprehensive, informative, relevant, and affordable. To facilitate progress in developing operational landscape monitoring, NPS, Parks Canada Agency, NASA, and other agencies co-sponsored workshops to share experiences and knowledge (NARSEC 2005, 2007; Gross et al. 2009). A clear need identified at these workshops was for organized teams of experts to focus on developing general methods, at relevant scales, that could be widely applied in order to distribute and share the costs of development. It is simply too difficult and expensive for individual parks or I&M Networks, on their own, to undertake development of a full suite of landscape dynamics monitoring protocols. To address needs for broad-scale data on landscape attributes across the entire system of parks, the I&M Program Office developed the NPScape project. NPScape provides landscape-level data, methods, tools, and evaluations for a limited set of attributes derived from data on land cover, population and housing, roads, and land ownership (NPScape 2010). Data and results from NPScape are provided for all of the more than 270 I&M park units. A central goal of NPScape was to reduce per-park costs by identifying and documenting a small set of highly relevant landscape-scale measurements that could be derived from national-scale data, and then centralizing data acquisition, processing, analysis, and reporting. NPScape is founded on the principle of economy of scale, and the huge variations in park geographical location, ecological context, and size make it impossible for NPScape to address many questions that require park-specific data or other local data. Although the needs for landscape-scale monitoring in and around Canadian parks differ somewhat from those in the US, Parks Canada Agency found they were in a similar position. In response to these needs, Parks Canada Agency and the Canadian Space Agency co-funded multi-year studies to develop and enhance operational use of remotely sensed data for park monitoring (Fraser et al. 2009).

While NPScape and other national programs will meet many NPS needs for broad-scale, relatively coarse resolution indicators, there remained a need for complementary monitoring protocols that operate at finer resolutions, that can address park-specific contexts, but that are still broadly relevant and easily adopted by and incorporated into NPS I&M. The goal of this report is to describe a project that focused on addressing this need, and to facilitate further progress in using remotely sensed data to support the management of protected areas. We describe a multi-year effort that worked with geographically dispersed parks from a variety of settings. This report provides a case study, illustrating approaches and results that will help implement routine use of remotely sensed data for monitoring in and around parks. We describe the rationale, design, and products of a project to enhance use of NASA data and technology by NPS I&M. While we focused on the needs of NPS I&M, the

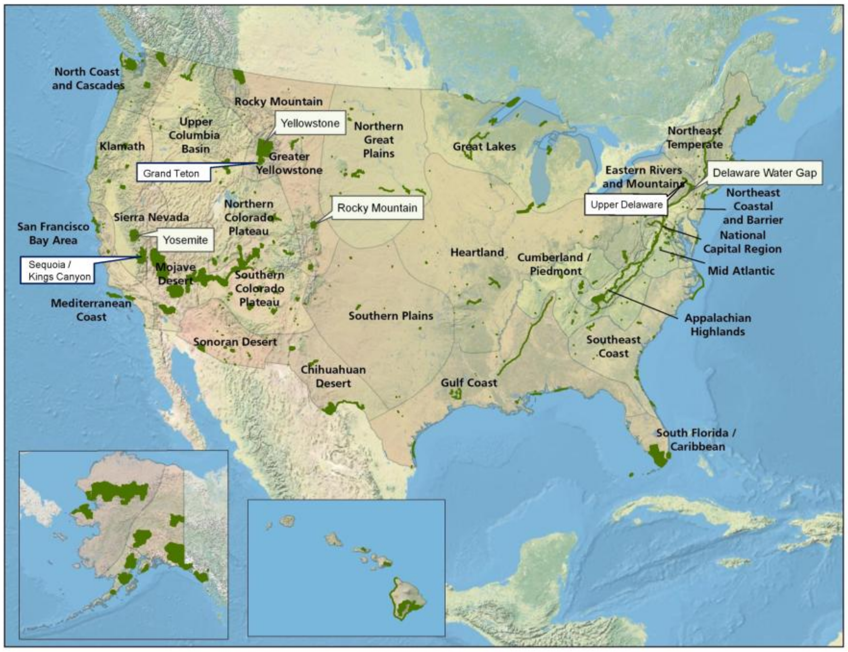

Figure 1. Map of the U.S. National Park Service ecoregional Inventory and Monitoring (I&M) Networks for the continental U.S. (Alaska and Pacific Islands not shown). Each Network consists of staff and infrastructure to support long-term ecosystem monitoring for natural resource parks within the Network. Focal parks (names in boxes) are served by the Sierra, Greater Yellowstone, Rocky Mountain, and Eastern Rivers and Mountains Networks.

issues, approaches, and results are broadly applicable to monitoring many types of protected areas. Other sources provide detailed reviews of the NPS I&M Program (Fancy et al. 2009; http://science.nature.nps.gov/im/index.cfm), conceptual frameworks that support landscape-scale monitoring (Hansen and DeFries 2007; Jones et al. 2009), and technical considerations that must be addressed when designing remote sensed based monitoring indicators (Phinn et al. 2003; Kennedy et al. 2009; and papers in Gross et al. 2009).

PALMS: Park AnaLysis and Monitoring Support

The overall goal of the PALMS (Park AnaLysis and Monitoring Support) project was to enhance the quality of natural resource management in parks by better integrating the routine acquisition and analysis of NASA Earth System Science products and other data sources into NPS I&M. NASA supported the project via a program that specifically targets science applied science (versus basic research). Each participating I&M Network and the national I&M office supported the project by allocating time of personnel with expertise that would contribute to the project. This included time of GIS/data specialists and ecologists with local knowledge of focal parks. I&M Networks also served as liaisons with the (much larger) park staff, thereby ensuring participation of decision-makers and others when appropriate. We felt the explicit contribution of NPS resources to the project was important to encourage shared ownership of results, and to sharing risks that might result from inadequate engagement.

Specific objectives of PALMS were to:

1. (a) Identify NASA and other products useful as indicators for NPS I&M monitoring, and (b) delineate the boundaries of the surrounding protected area centered ecosystems (PACE) appropriate for monitoring.
2. Add value to these data sets for understanding change through analysis and forecasting.
3. Deliver these products and a means to integrate them into the NPS I&M decision support framework.

The project focused on four sets of national parks to develop and demonstrate the approach (Figure 1): Sequoia-Kings Canyon and Yosemite National Parks (Sierra Nevada I&M Network), Yellowstone and Grand Teton National Parks (Greater Yellowstone I&M Network), Rocky Mountain National Park (Rocky Mountain I&M Network), and a combination of Delaware Water Gap National Recreation Area and Upper Delaware Scenic and Recreational River (Eastern Rivers and Mountains I&M Network). Selection of focal parks was based almost entirely on the familiarity of the principal investigators with these parks, and access to data and resources that supported the goals of the project. Other parks and Networks were keen to participate in this project, but we lacked the capacity to expand the study and include additional parks. An expanded, follow-on project is pending.

PALMS was designed from the outset to be highly collaborative. All the investigators were experienced, had worked with NPS, and had some idea of the type and extent of communication that would be required. The explicit contribution of staff time from each participating I&M Network clearly promoted this approach. Nonetheless, a surprisingly substantial and sustained effort by all project staff was required to keep park and Network collaborators informed and engaged throughout the project. Park personnel, especially those in supervisory positions, tend to have many fixed-time commitments that made scheduling complicated. When working with parks, the time required to schedule meetings or provide products and obtain reviews can be considerable.

PALMS Ecological Indicators

Every monitoring project must balance the desire to deliver the most comprehensive, useful, and interesting information with constraints imposed by technical feasibility, cost, staff expertise, and available resources (Phinn et al. 2003; Jones et al. 2009; Kennedy et al. 2009). All NPS I&M Networks undertook a multi-year effort to identify high priority vital signs before we initiated this project and "landscape dynamics" was consistently ranked among the highest of all monitoring needs. Beyond identifying the need for landscape-scale monitoring, few Networks had identified any specific variables for monitoring. Furthermore, Networks clearly understood the importance of landscape changes outside parks boundaries (GAO 1994; Parks and Harcourt 2002; Hansen and DeFries 2007), but all Networks were struggling to define the boundaries of scientifically credible and defensible areas for monitoring landscape-scale changes outside park boundaries.

Our first step was to identify candidate indicators for further development by consulting I&M Network monitoring plans and related documents – i.e., glean what we could from existing information (Jean et al. 2005; Britten et al. 2007; Marshall and Piekielek 2007; Mutch et al. 2008). I&M monitoring plans described park resources and threats to resources, existing and planned monitoring, and related information that could help identify suitable indicators. We held a series of meetings with park and Network staff to discuss and refine definitions of indicators, and we also relied on our collective experiences and expertise. The process of identifying and refining indicators was iterative, and the final resolution of some indicators took more than two years of discussion and development. All forms of inputs proved to be valuable contributions to the final selection and development of the indicators.

The complete set of PALMS indicators and their geospatial attributes is summarized in Table 2. The suite of PALMS indicators includes measurements of weather and climate, stream health (water), land cover and land use, disturbances, primary production, and monitoring area. In the following sections, we briefly summarize features of exemplar indicators that are novel to this project or that are otherwise of particular interest. More complete descriptions of methodology and results are available in the descriptions of PALMS products (below) and in other publications (Goetz and Fiske 2008; Nemani et al. 2009; Goetz et al. 2009; Theobald et al. 2009; Jantz et al. 2010; Theobald 2010; Wade and Theobald 2010, Wade et al. in review, Theobald et al. in review, Bierwagen et al. in press; Hansen et al. in review).

Protected Area Centered Ecosystems (PACE)

Identifying a suitable area of analysis (AOA) is challenging because the extent of the most appropriate AOA varies with the specific issue, process, or species that is of most interest. Ideally, a long-term monitoring program would simply define an AOA that encompassed the broadest-scale issue anticipated. This is an impractical solution for most parks because the cost of imagery acquisition, processing, and analysis is directly related to the size of the AOA. There is thus a strong incentive to constrain many analyses to the smallest area necessary. Following Hansen and DeFries (2007), we developed a framework for delineating the ecosystem surrounding a protected area that is likely to strongly influence ecological function and biodiversity within the protected area. Termed "Protected Area Centered Ecosystems" (PACE; Hansen et al. submitted), this area becomes the logical place to focus monitoring, research, and collaborative management in order to maintain protected area function

Table 2. Indicators selected for development by PALMS, and some of their attributes.

Level	Category	Indicator	Extent[1]	Resolution
Air and Climate	Weather and Climate	Phenology (Normalized difference vegetation analysis – NDVI), annual anomaly)	CONUS	1 km (all); 8 & 16 day
		Climate gridded daily 1980-2010	YOSE, ROMO, YELL, YOSE	1 km
		Climate scenarios (monthly)	YOSE, DEWA, GYE, CONUS	12 km
Water	Stream health	Bioitic Index of Biological Integrity, Sensitive taxa	DEWA	1:24K, 1:100K
Landscape dynamics	Land Cover	Ecosystem type composition Summary by spatial scale	DEWA, ROMO, YELL, YOSE	30 m
		Bird hotspots and key habitat types	GYE	1 km
		Impervious cover change	DEWA	30 m
		Housing density class (1940 – 2100, decadal)	CONUS	100 m
		Landscape connectivity of forests	Eastern US	270 m
		Pattern of natural landscapes	CONUS	270 m
		Past to future modeling	DEWA	30 m
	Extreme Disturbance Events	Fire effects via changes in phenology and related measures	DEWA, ROMO, YELL, YOSE	1 km; monthly anomalies / annual summaries
	Primary Production	Gross and Net primary productivity (via simulation model results)	DEWA, ROMO, YELL, YOSE	1 km daily and/or monthly summaries; annual trends
	Monitoring area	Greater park ecosystem boundaries	DEWA, ROMO, YELL, YOSE	30 m
	Land use	Land use	CONUS	90 m

[1]CONUS = continental US (lower 48 states), DEWA = Delaware Water Gap National Recreation Area (including Upper Delaware Scenic and Recreational River), GYE = Greater Yellowstone Ecosystem, ROMO = Rocky Mountain National Park, YELL = Yellowstone National Park, YOSE = Yosemite National Park.

and condition. The PACE framework is founded on five ecological mechanisms (processes) by which human activities impact ecosystem functioning (Table 3). The PACE served two very important purposes. First, it defined a spatial context for conducting analyses and reporting results. Second, it is, by itself, an indicator of landscape condition, because the shape, composition, and extent of the PACE responds to and reflects human impacts in the area around a park.

To illustrate the approach in a variety of geographic and land use settings, we defined PACEs for the NPS units included in the PALMs project and in two additional regions (the Pacific Northwest and the Appalachian Highlands). The resulting PACEs were on average 6.7 times larger than the parks for those in upper watersheds and 44.6 times larger for those in mid watersheds (Figure 2). PACEs in the eastern US were dominated by private lands with high rates of land development, suggesting that they offer the greatest challenge for management. Our NPS collaborators generally embraced this approach for delineating the area to be monitored around national

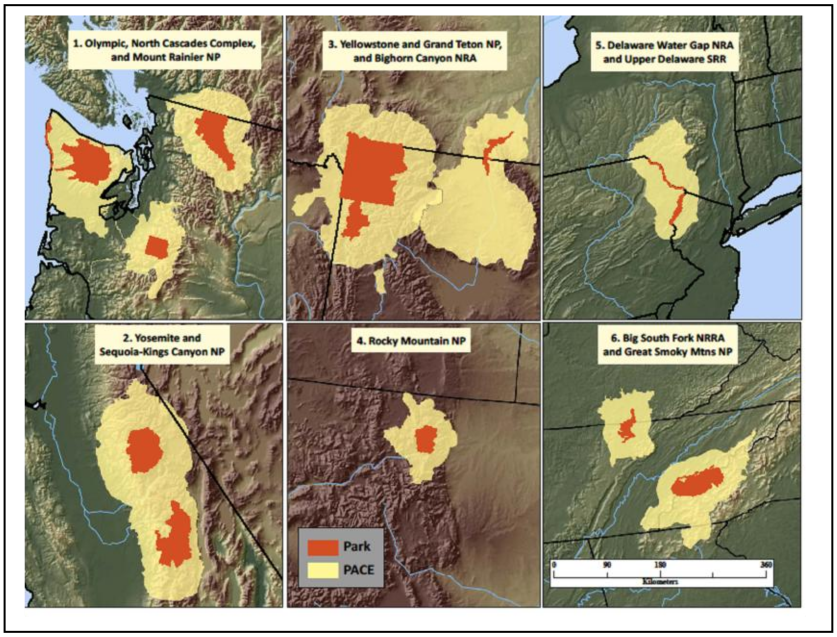

Figure 2. Maps of protected-area centered ecosystems (PACEs) delineated in this study for 13 U.S. National Park units. PACEs were defined by the criteria in Table 3.

Table 3. Mechanism, rationale, and criteria used to define the Protected Area Centered Ecosystem (PACE). (adapted from: Hansen and DeFries 2007 and Hansen et al. submitted).

Mechanism	Rationale	PACE criterion
Change in effective size of reserve	Fewer species are supported in small areas; species can be lost as habitats are isolated	Specific habitat areas in the PACE are proportional to those in the park, up to the area specified by the species-area relationship
Changes in ecological flows into and out of reserve	Water, sediments, nutrients, hydrological patterns may be altered by upstream land uses	Watershed boundaries around park; subbasins or subwatersheds that intersect parks.
	Atmospheric transport of dust and pollutants affect parks; upwind land use can affect local climates	Airsheds based on sources of pollutants or climate
	Disturbances that originate outside parks can move into parks; conditions in initiation and run-on zones affect likelihood of disturbance and provide key habitats	Perimeter around park based on historic disturbance rates, size, and shape.
Loss of crucial habitats	Includes seasonal habitats or ranges, movement paths, source populations, and parts of large home ranges that are outside of parks and that may be altered or destroyed.	Key habitats for migration, seasonal use, or otherwise crucial for park organisms (requires local knowledge)
Edge effect due to human activity	Human activities in areas adjacent to parks can directly or indirectly disturb or kill wildlife. Examples include hunting, poaching, pets (dogs, cats), introduction of exotic species,	Create 25 km buffer around park and select human dominated areas; create 5 km buffer around crucial habitat polygons.

parks and suggested that the approach helps facilitate research and conservation across the parks and important surrounding lands.

Stream Biota

Stream macroinvertebrate diversity is a commonly used indicator of aquatic health, reflecting overall ecological integrity within a watershed (VanSickle et al. 2006). Urbanization and associated impervious surface cover have adverse effects on aquatic systems, including greater variability in stream flow (flashiness), lower base flows, and increased bank and stream bed erosion (Scheuler et al. 2009). These effects can be mitigated by near-stream vegetation buffers and other actions that reduce the force of overland flows, absorb excess nutrients, maintain stream bank integrity, and provide shade that reduces warming of stream water (Snyder et al. 2003). We mapped and modeled these processes in watersheds that encompass the Upper Delaware Scenic and Recreational River (UPDE) and the Delaware Water Gap National Recreation Area (DEWA). Of primary interest to the Eastern Rivers and Mountains Network, and more generally to the NPS I&M effort, is information on stream biota and how these are likely to be impacted by expanding urbanization, including low density residential development. We addressed this need by adapting statistical models of the relationship of stream health indicators developed in data rich watersheds of the mid-Atlantic region (Goetz and Fiske 2008). These models were based on relating in-situ observations from the Maryland Biological Stream Survey (Roth et al. 2004; Kazyak et al. 2005) to land cover variables, translated into relatively simple procedures that can be conducted in a Geographic Information System (GIS) environment (Goetz and Fiske 2010). The procedures allow prediction of the richness and abundance of stream macroinvertebrates, as well as integrated indices of stream biological integrity. Because the models use land cover metrics to predict the variation of stream biotic metrics, they can be used across small watersheds as indicators of stream impairment and thus to focus monitoring, restoration and protection management objectives. An example prediction of the diversity of Ephemeroptera, Plecoptera, and Tricoptera species (nEPT; genera are mayfly, stone fly, and caddis fly, respectively), which are known to be sensitive to stream pollution and sedimentation, is shown in Figure 3.

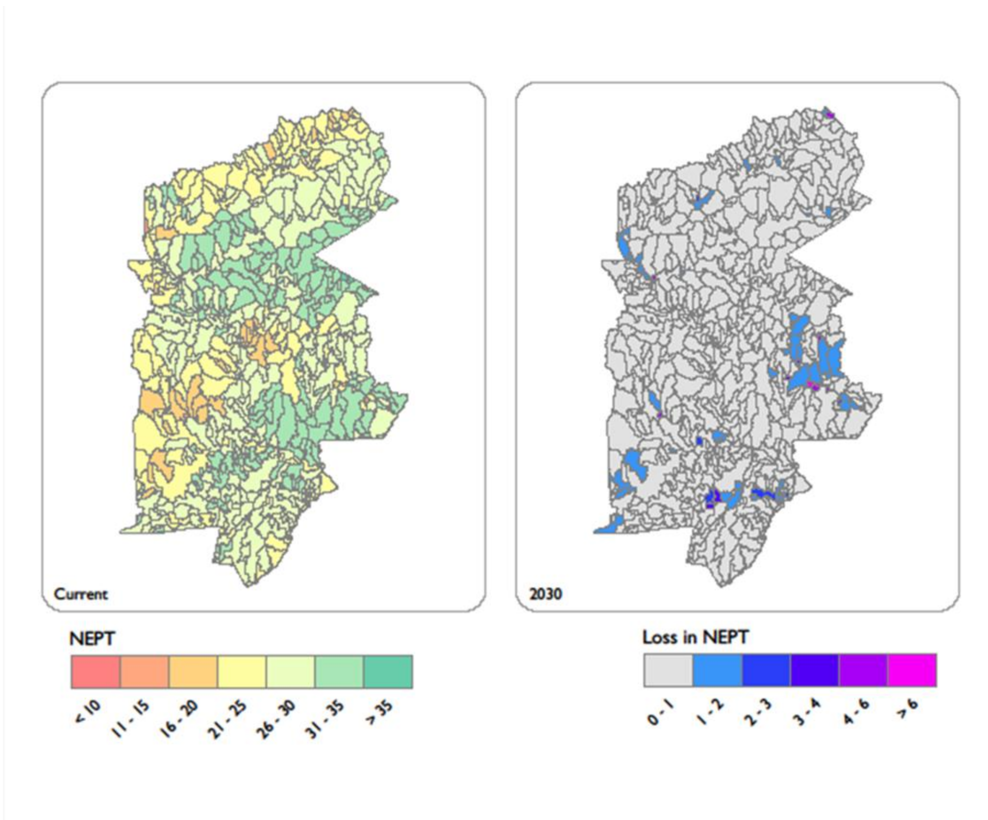

Figure 3. Maps of the Upper Delaware river basin showing the predicted number of sensitive stream taxa (abundance of EPT species; see text) for the present (left) and as predicted to change by 2030 using future land cover based on simulations of continued urbanization trends for watersheds (right).

Future predictions of urbanization under different land management scenarios, where they exist, can also be used to assess the potential impact of impervious cover in new residential and commercial developments on stream biota. As part of PALMS, we developed such predictions (Jantz et al. 2010) and used them to predict the status of future stream biotic condition, as expressed by the nEPT (Figure 3). The results clearly show the potential for reducing the impacts of impervious areas through mitigation measures such as maintaining riparian buffers and overall natural vegetation cover within a watershed.

Watershed biotic diversity maps of this sort, based on land cover variables, provide a baseline against which in-situ stream measurements can be compared and assessed as NPS monitoring programs develop. Moreover, the predictions are useful to I&M and park staff as they evaluate the sampling design for long-term monitoring of stream health and assess the risk of future residential and commercial development on aquatic biota.

Connectivity

Habitat fragmentation poses one of the foremost threats to biodiversity in US parks and other protected areas (Hilty et al. 2006). Fragmentation is generally caused by loss of habitat, and results in the isolation of parks. Isolated parks are unable to support levels of biodiversity that existed prior to landscape changes (Newmark 1986; Parks and Harcourt 2002), and the ability of animals to move between large tracts of natural habitat is necessary to sustain the full range of biota and ecological processes in parks.

Connectivity of landscapes for the conterminous US was estimated using an application of GIS-based least-cost distance methods that provides two novel aspects. First, this approach does not require patches to be first identified, as do patch-matrix approaches. Rather, the method considers the landscape as a gradient (Kupfer et al. 2006; McGarigal et al. 2009), which better reflects the gradual transitions that commonly occur between many land cover types. Second, the method provides a quantitative estimate of the importance of each linkage or movement pathway. The application of these quantitative estimates can assist selection and prioritization of local and on-the-ground efforts.

Two products were generated from our approach. First, four cost-distance maps, each reflecting the weighted distance from the left, right, top, and bottom of the map extent, are averaged together to compute an overall landscape connectivity surface, similar to traditional least-cost "corridor" maps generated from the average value from two cost-distance maps (Theobald 2006; Beier et al. 2006). This map is useful to understand general patterns of natural landscapes, where additional information about the landscape configuration is added. Permeability to movement was estimated by the "naturalness", N, which ranged from 1.0 (natural) to 0.0 (intensely human-modified) at 270 m resolution as a function of land cover types, housing density, presence of roads, and effects of highway traffic (Theobald 2010). Resistance values (or cost-weights) were calculated as 1 / N. Second, pathways that flow across the surface maps are found, similar to the flow of water across the terrain forming dendritic networks (Figure 4). Rather than forming a hydrologic network, a network of potential movement pathways is formed. The flow accumulation is weighted by N at each pixel, so that movement pathways incorporate both the pattern of movement, as well as the importance of that movement. This flow-accumulated value is a computationally efficient approximation of the 'betweeness' centrality measure (Borgatti 2005).

Identification of corridors by this approach has proved useful to parks. A key attribute of the method is the clarity of the result. 'Dendritic' corridors identified by the method were easily interpreted, and they were very intuitive to park staff and partners. The approach permits calculations over very large grids (> 108 cells), hence we were able to provide results that identified important corridors at local to continental scales. These results are valuable to parks because they clearly communicated the important role of parks as links in pathways that provide for very broad scale movements (Figure 4). Results for DEWA, in particular, aligned very well with landscape scale connectivity assessments (Goetz et al. 2009) and on-going local conservation efforts. Local-scale analyses had identified high-priority areas for conservation at a fine scale, but they had not identified or realized how these local corridors would likely contribute to regional-scale conservation.

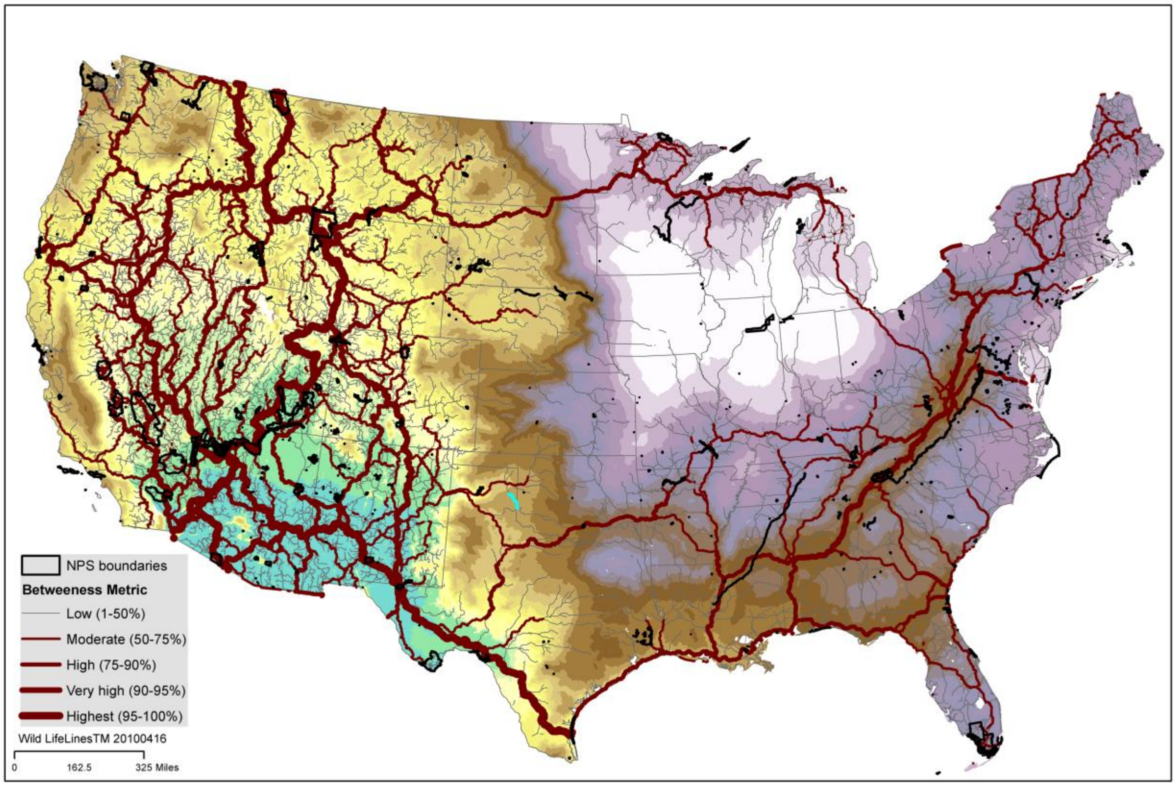

Figure 4. Map showing connectivity of natural landscapes in the U. S. The thickness of red lines indicates magnitude of cumulative movement, assuming that animals avoid human-modified areas. The surface underneath the pathways depicts the averaged cost-distance surfaces, or the overall landscape connectivity surface. Colors range from green through yellow and purple to white, where green is greatest connectivity (lowest travel cost) and white indicated lowest connectivity (highest travel cost). National Park units are outlined in black.

Land Surface Phenology

Variability and trends in the timing of seasonal biological events (phenology) are thought to be responsive indicators of global change (Schwartz 2003; Morisette et al. 2009). The onset and length of growing season through their impact on primary production or simply plant growth are excellent indicators of ecosystem function with broad consequences for biodiversity. For example, spatial and temporal patterns of grassland and shrubland productivity in and near Yellowstone National Park are of particular interest due to their importance to migratory elk and bison (NRC 2002; White et al. 2010). These seasonally migratory ungulates have historically crossed public-private land boundaries in search of high-quality forage and to avoid deep snow during winter months, sometimes creating conflicts between land owners and wildlife managers. Working with the PALMS team, Yellowstone National Park staff identified forage phenology as a high priority indicator, with a desire to better understand how land use and climate patterns influences forage availability and thus the spatial distribution of ungulates.

PALMS developed multiple phenology indicators based on NASA MODIS 250 m NDVI (Normalized Difference Vegetation Index) data products (Justice et al. 1998; Huete et al. 1999; Huete et al. 2002). For a pilot study centered on the Yellowstone Northern Range, we created annual NDVI curves and calculated phenology metrics based on properties of those curves for each eight-day interval for 2003-2009. These phenology metrics included measures of date of spring green-up, length of the growing season and peak annual NDVI (White et al. 2009; deBeurs and Henebry 2010). Collectively, these metrics describe annual characteristics of grassland growth across space and interannual patterns of growth through time. We separated habitats that provide ample grassland cover for ungulate foraging and incorporated these into an annual, three-dimensional animation of greenness to help park staff visualize patterns of forage productivity at the landscape scale in and adjacent to their park. Further investigation of the spatial and temporal dimensions of grassland productivity is demonstrating the degree to which productivity is influenced by climate and land use. With interacting effects, land use and climate change have the potential to significantly alter spatial and temporal patterns of grassland productivity in the Greater Yellowstone Ecosystem in ways which will increase the likelihood of future conflicts between private land owners and wildlife. One intended use of phenology measurements is to use phenology as a leading indicator of animal movements, thereby enabling Yellowstone National Park managers to anticipate animal space use and plan strategies to mitigate conflicts with private landowners in areas surrounding the park.

Phenology was also identified as an indicator of interest for the other partner I&M networks. In the west, shifts in phenology and the length of the growing season may affect hydrologic patterns and the timing of periods of peak vegetation water stress, with potential consequences for fire management practices. For all parks, shifts in phenology also have implications for visitor management, as many visitors plan visits around various phenological events, such as wildflower blooms, changes in vegetation foliage, and animal migrations. Finally, since land surface phenology is closely linked with climate, sustained trends in phenological dates can provide an early indictor of climate change impacts. The Terrestrial Observation and Prediction System (TOPS) (Nemani et al., 2009) was applied to produce time series of vegetation phenology from 2001 to present from MODIS 1km NDVI data (MOD13A2) for the PACE surrounding the parks within each of the partner I&M networks. Multiple phenology algorithms were implemented within TOPS, and in response to requests from NPS partners to provide justification for selection of a particular approach to calculating phenologic metrics, the $\text{Midpoint}_{\text{Pixel}}$ algorithm was selected based on results from White et al. (2009), which identified the $\text{Midpoint}_{\text{Pixel}}$ as one of the two phenology algorithms which correlated most closely with ground observations of various phenologic indicators.

For each partner I&M network, phenology timeseries were produced for the Start of Season (SOS) date. Maps of SOS anomalies were produced annually, and trends were calculated for SOS dates summarized by park boundary, elevational band, and ecosystem type. These maps and charts were distributed to partner I&M networks via the TOPS Ecocast web interface (described later in this report). The TOPS Ecocast framework provides a dynamic interface that allowed NPS partners to explore recent spatial and temporal patterns in phenology within parks and the surrounding PACE, and to summarize patterns for particular regions of interest. Data and summary charts and graphs can be downloaded from the Ecocast interface to facilitate use in reports to management. Methods for production of the phenology dates were described in an SOP developed in collaboration with the Sierra Nevada Network (SIEN) (Melton et al., 2010).

Primary Production

Gross primary production (GPP) is the rate at which plants and other producers in an ecosystem capture and store energy as biomass via photosynthesis. Some fraction of this energy is used to maintain existing tissues or is lost through plant respiration, and net primary production (NPP) is the remaining amount that is 'fixed' or stored by an ecosystem. As indicators of ecosystem productivity, GPP and NPP provide an integrative measure of ecosystem condition that incorporates seasonal climatic influences and satellite measures of vegetation condition, as well as information on topography, soils and water availability.

To characterize ecosystem productivity for each of the partner I&M Networks, we followed the general approach employed by the MODIS MOD17A2 algorithms (Running et al., 2000) and applied a simplified version of BIOME-BGC ecosystem model (Thornton et al. 2002; Thornton et al. 2005) within TOPS (Nemani et al. 2009). TOPS is a modeling and climate and satellite data assimilation framework maintained by NASA Ames for use in ecological forecasting and ecosystem modeling research and applications. Relative to standard MODIS productivity products, TOPS uses gridded climate data at a much finer spatial resolution (1 km) to account for the steep, heterogeneous terrain in many of our partner I&M Networks and parks. TOPS uses satellite-derived estimates of leaf area to estimate various water (evaporation, transpiration, stream flows, and soil water), carbon (net photosynthesis, plant growth) and nutrient flux (uptake and mineralization) processes on a daily time step. BIOME-BGC requires as inputs spatially continuous data layers to describe the land cover, soil texture and depth, daily meteorology, and elevation across the land surface. To evaluate spatial and temporal patterns in GPP, daily maps were produced for the PACE surrounding each of the focal parks for the period from 2001-2010. Feedback from collaborators indicated that daily and monthly GPP maps were useful, but difficult to translate into summary products. We thus compiled the GPP data into seasonal and annual summaries of cumulative GPP (Figure 5) by park, PACE, and major ecosystem type, and evaluated the data to characterize baseline conditions for future monitoring and identify any emerging trends over the past decade. A SOP was prepared for the productivity products (Melton et al. 2010), and the summary products were distributed via a dynamic web interface (Figure 6).

Patterns in GPP varied by park, region, and ecosystem type. For example, in the Sierra Nevada parks, the indicator captured the significant interannual variability in productivity driven by year to year variations in the timing of snow accumulation and melt. In contrast, parks in the Eastern Rivers and Mountains I&M Network showed sustained declines in GPP over the past decade, which may be due in part to increasing tree mortality resulting from infestations of the hemlock wooly adelgid (Adelges tsugae) throughout the region. While a ten-year data record is too short to identify long term trends, the indicator was shown to capture the impact of climate variation and disturbance events on ecosystem condition.

Modeling Climate Change Impacts

Understanding potential climate change impacts continues to be a high priority for NPS, and the recently completed NPS Climate Change Response Strategy (NPS, 2010) outlines the key elements of the NPS approach to addressing climate change within national parks. Key components of the NPS strategy include investments in scientific understanding, adapatation and mitigation efforts, and communication and public outreach.

Through this project, we explored the potential for NASA data and models to contribute scientific information to assist NPS is identifying potential climate change impacts to national parks and ecosystems within the surrounding PACE. Climate change scenarios were produced for Yosemite National Park using TOPS (details of the analysis and results are described in Nemani et al., 2009). Results from the analysis conducted using TOPS identified likely shifts in the timing of snow melt and runoff, and reductions in summer streamflow and water availability, consistent with previously published results for the Sierra Nevada. The analysis also quantified the potential impact of the hydrologic shifts on vegetation productivity, predicting an increase in GPP during the Spring, but significant declines in peak productivity during the summer months, resulting in an overall decline in annual vegetation productivity. The TOPS forecasts assisted NPS collaborators in understanding the magnitude of the potential impacts of climate change on vegetation productivity in the park, the linkage between changes in hydrology and indicators of ecosystem condition, and the timeframe in which these impacts were likely to occur, with significant impacts predicted to occur by 2050.

At the time the analysis was completed, however, NPS was still in the process of developing its climate change response strategy. In addition, it was clear from discussions with NPS that integration of NASA data products and capabilities for assessing climate change impacts would be a substantial undertaking, would require involvement of multiple Federal agencies, and would require a focused effort deserving of its own, well defined project. The PALMS project team has submitted a proposal to NASA to address this need, which directly builds on the experience of assessing climate change impacts in collaboration with the NPS Sierra Nevada Network under this project, and which takes advantage of advancements in both the TOPS information architecture completed under this project, and the substantial ongoing improvements in the NPS I&M information architecture.

Effectively Delivering Results to the National Park Service

There was an unusually high rate of turnover in cooperating NPS staff during our project, which led us to reconsider our plans for transferring PALMS products and knowledge to NPS. We had planned to place a high priority on training individual staff that would serve as NPS experts on PALMS products and methods. This strategy involved considerable investment in individuals, and that investment would be lost if they left their NPS positions. We consulted NPS collaborators and concluded that the most effective means for transferring project results included NPS-hosted web sites, a set of site-specific project completion calls, park-specific reports, datasets, detailed methods (SOPs, see below), and peer reviewed publications. This variety of products clearly reflected the general desires articulated by park managers in an earlier survey (Hubbard 2006). The suite of products and close-out activities we employed are, in our experience, rather unusual, and we believe this can serve as a good model for many projects that seek transfer of knowledge and technologies to specific partner programs or agencies. The following sections describe our strategy in more detail.

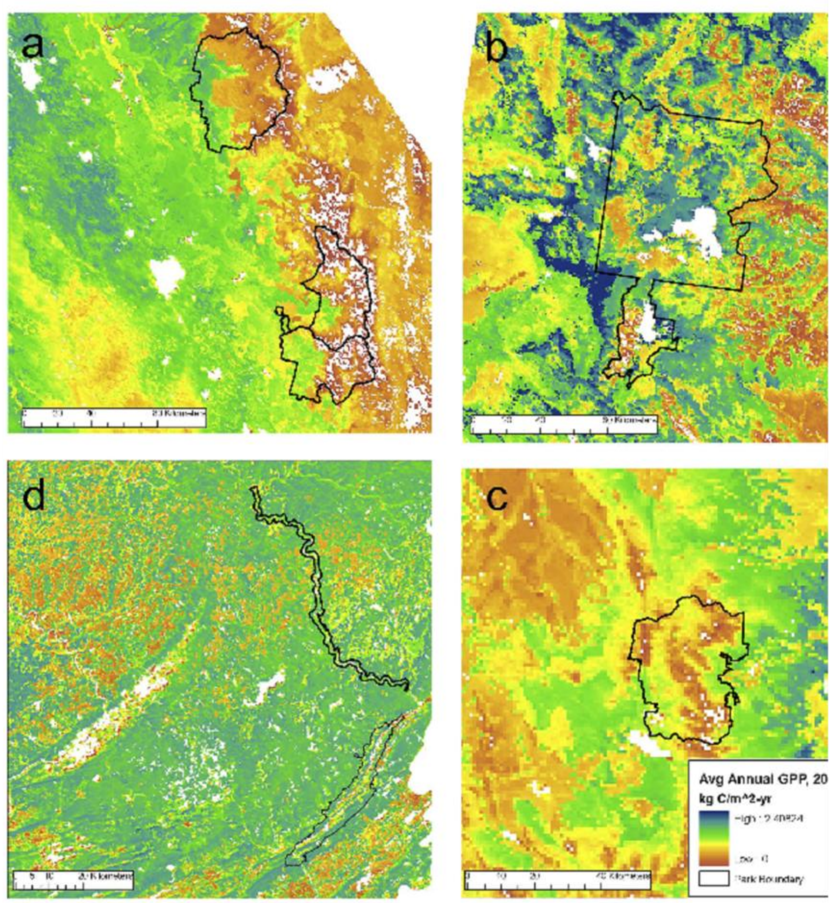

Figure 5. Daily estimated GPP (gross primary production) was summarized to convey spatial and temporal patterns in productivity in the parks and surrounding ecosystems. Maps of average annual total GPP for 2001-2009 are shown for these National Park Service units: (a) Yosemite/Sequoia-Kings Canyon, (b) Yellowstone/Grand Teton, (c) Rocky Mountain, (d) Delaware Water Gap / Upper Delaware.

Documentation of Indicators and Methods

Our project partners felt that 1-2 page “resource briefs” on individual indicators would effectively communicate results to decisions makers and serve as quick introductions to the indicators for ecologists and other resource professionals. Each brief included a short description of the indicator issue, why it was useful, and a very short (1-2 paragraphs) summary of results. Results were always illustrated with one or more maps, tables, and/or graphs. For each park, the briefs were combined into a single package (document) that included an abstract, table of contents, one-page overview of the project, and table similar to Table 2.3 with information on all the indicators for that park. The set of briefs did not include details on methods, and they included only the highlights of results. Recipients found the set of briefs to be much more accessible than a technical report or peer-reviewed publication.

A fundamental goal for PALMS was to develop indictors and methods that would be adopted by NPS I&M. A major impediment to adopting an indicator or new method is the cost of development of an approved protocol. All NPS I&M Networks are required to develop a detailed, peer-reviewed protocol that meets published guidelines for each indicator they monitor (Fancy et al. 2009; Oakley et al. 2003). These guidelines were established to ensure that I&M monitoring procedures are completely documented and remain consistent through time and across changes in personnel. The work required to write a complete protocol is usually well beyond the scope of an externally funded research or development project, but projects may be able to draft parts of protocols and greatly reduce the time and cost required to complete a protocol.

Protocols compliant with NPS I&M standards consist of a narrative describing the goals and overall approach of the protocol, and a set of Standard Operating Procedures (SOPs) that describe, in detail, the specific procedures for a discrete task or operation. The PALMS team focused on writing SOPs for the core procedures for calculating each project indicator. These SOPs are highly detailed documents that permit I&M staff to repeat analyses or conduct the same analysis on new data sets. SOPs contain more details than the methods section in a typical peer-reviewed paper. For protocols that rely on GIS software and remotely sensing data, SOPs are usually illustrated with screen shots of key steps and, when appropriate, include step-by-step instructions for computer procedures.

To facilitate replication of GIS-based PALMS analyses, we developed ArcGIS (ESRI 2009) tools with Arc ModelBuilder. These tools automated complex or repetitive tasks, and served to reduce the level of software-specific expertise needed to reproduce our results or to repeat analyses with other data sets for different locations or time frames.

Web Sites

The range of products from PALMS is probably typical of a large, complex, multi-agency monitoring development project. The large number of products, diverse array of product formats, extended period for delivery, and large volumes of data motivated the use of a tiered web site to communicate and deliver products to project and park participants. We developed a public web site on an NPS server for posting SOPs, reports, links to related sites, and links to data or information for acquiring large data sets. Because NPS was the target 'client', the use of an NPS server (rather than one hosted elsewhere) helped ensure delivery of all relevant products and methods to NPS and it increased the likelihood that products would be properly catalogued, archived, and remain accessible to NPS staff for the long term. These web sites will be removed as the required quality checks are completed and the products are fully integrated into and retrievable from the NPS information system.

Sustained interactions with park-based personnel required the addition of site-specific web pages that supported the completion calls (see below) and facilitated review and discussion of products as they were being developed.

Dynamic Web Interfaces and Data Services

Satellite data analysis and ecosystem modeling are specialized fields, and park managers may be unfamiliar with satellite-derived indices and model parameters (e.g., NDVI, leaf area index, GPP, NPP), presenting a barrier to their adoption and use in park monitoring. To address this challenge, we developed a dynamic web interface based on the TOPS Ecocast framework (Figure 6) to present visual examples to NPS collaborators and to demonstrate how indicators derived from satellites and ecosystem models could be applied to characterize spatial and temporal patterns in park ecosystem conditions. This interface utilized open source tools and software libraries to provide an interface that was driven by an OPeNDAP data server (http://www.opendap.org/) and included dynamic web maps to characterize spatial patterns, and graphs and charts to summarize temporal patterns in the satellite- and model-derived indicators. This interface was effective in providing concrete examples of the use of the satellite and model data to dynamically summarize park ecosystem conditions.

To be sustainable as long-term I&M indicators, the source data used to calculate indicators must be readily accessible via data services and tools that are compatible with NPS information systems. Source data are needed to allow I&M Networks to update indicators, and to develop customized analyses and summaries that can address park-specific issues. The PALMS project used ArcGIS (ESRI 2009) compatible geodatabases to store and distribute data for many of the PALMS indicators. We also tested the use of open source software for data distribution, including an OPeNDAP server (Open-source Project for a Network Data Access Protocol; http://www.opendap.org/), which was used to distribute satellite and ecosystem model results from TOPS (http://ecocast.arc.nasa.gov/opendap). OPeNDAP is optimized to distribute large archives of raster data, such as those provided by TOPS, and it provides functionality for both temporal and spatial subsetting of geospatial data archives. ArcGIS tools are widely used within NPS and this approach had the advantage of providing data in a form that can be directly imported into I&M geodatabases and incorporated into NPS projects. NPS is currently enhancing the I&M data system with tools that automate data retrieval via web services, data transformation and analysis, and visualization of results. Data services used by the PALMS project are fully compliant with and support this growing I&M data infrastructure.

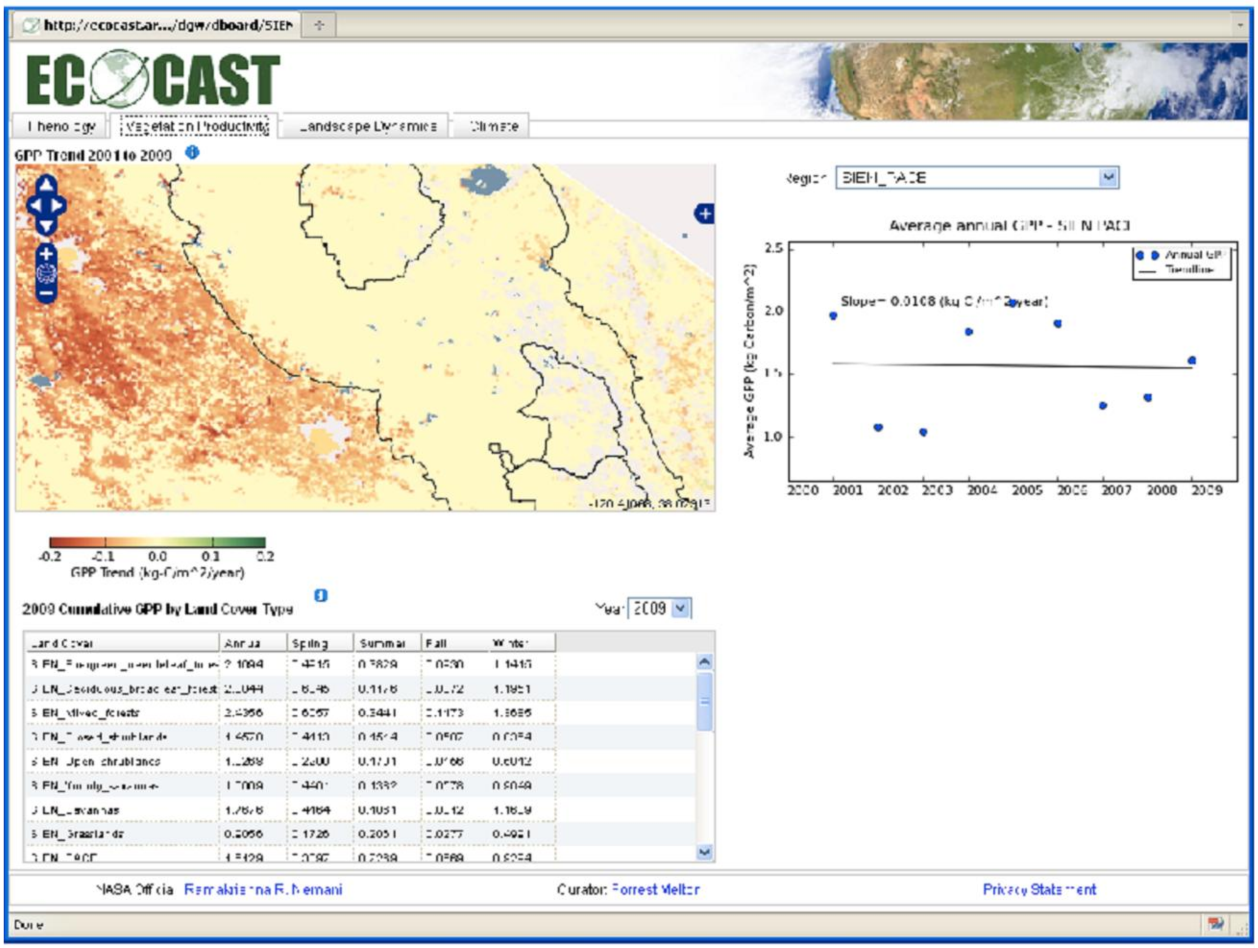

Figure 6. The Ecocast dashboard was used to display summaries of results for indicators directly estimated from remotely sensed data (e.g. phenology, snow cover), and results from simulations that estimated many other ecosystem variables e.g., gross primary production (GPP) illustrated here; see text for explanation). The Ecocast summaries included maps showing regions with emerging trends or anomalies, and graphs and charts summarizing patterns by park or PACE, time period, and/or ecosystem type.

Project Completion Calls

Several factors posed significant challenges to using traditional project meetings for presenting our results. The integrated nature of the project meant that all investigators contributed important results for all parks, but project and park personnel were located at more than a dozen sites across the U.S. The number and complexity of project indicators (Table 2.3) ensured that any presentation of all site-specific results would be an overwhelming volume of information. Furthermore, we were convinced that deep local knowledge was required to fully interpret our results and ensure that they addressed issues that were relevant and important to managers. Full interpretation required a series of conversations.

To meet these challenges, we scheduled a series of project 'completion calls' lasting about two hours. Each site participated in at least three webinars, and we scheduled additional webinars on specific results, methods or topics as required. Call participants included project staff, principal NPS collaborators from each park, and interested management staff. These calls seemed to be effective by delivering results in measured 'doses' and facilitating discussions of the results and outcomes. They also permitted time for park staff time to review and discuss results between calls, and for additional interaction that might be needed to clarify, refine, or revise our work. We conducted a total of 14 such sessions over the final year of the project.

Assessment of this Project by NPS Collaborators

Our first assessment report was based on responses to the questionnaire by the NPS collaborators at the end of the second year of the project. For this final assessment report, our NPS collaborators provided responses to the same questionnaire in December 2010 at the conclusion of the study. The methods and results of the assessment are presented in Appendix 2. Here we summarize and interpret the responses to the questionnaire.

Evaluation of the project is best done in the context of the project goals and objectives (pg 6) and proposed approach. The proposed approach for achieving the goal and objectives was based on the NASA Applications Program Framework and is represented in Figure 7. Within this framework, Earth observations and NASA ESS models are used as inputs to generate observations and predictions that enhance the NPS I&M DSS and inform NPS management decisions and policy. Our Objective 1 identified the indicators that would be developed via the

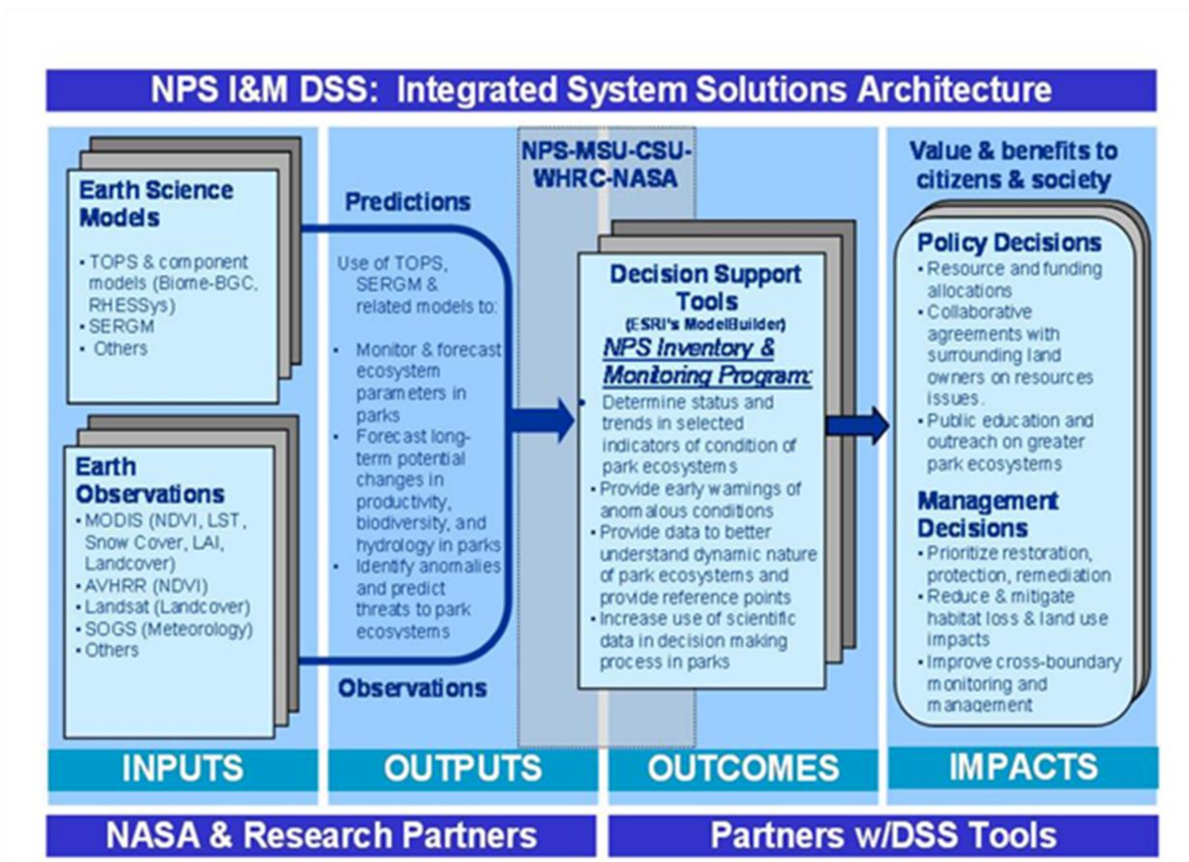

Figure. 1. Integrated System Solutions architecture for the proposed project. The project used NASA ESS observations and models to improve the NPS Inventory and Monitoring Programs DSS by hindcasting, nowcasting, and forecasting of park resources to aid management.

framework and the spatial areas around the parks where these indicators would be monitored. Objective 2 represented the Inputs and Outputs portion of the framework. Objective 3 represented the Outcomes panel of the framework where the results from Objective 1 and 2 were integrated into the NPS I&M decision support system. The ultimate goal of the project was to have our contributions to Outcomes provide inputs to Impacts as represented by policy and management decisions. This link between Outcomes and Impacts is largely within the jurisdiction of the NPS I&M partners and the NPS park staff, however, and was not an explicit objective of this project. The questionnaire was designed to primarily assess success in achieving Objectives 1-3, and to a lesser extent, the project's contribution to NPS policy and management decisions. Below we discuss the results of the questionnaire and add perspectives of the project P.I.s.

Were Expectations Met?

The results of the questionnaire and the view of the P.I.s is that expectations were very well met with regards to the three objectives. The respondents rated their overall satisfaction with the project as relatively high to very high.

Objective 1. The indicators identified under Objective 1(a) were rated as highly relevant by the cooperators and this rating increased over the course of the study. The list includes some highly advanced products that were not previously available to NPS I&M. Satellite and meteorological data where used to parameterize simulation models to estimate ecosystem productivity, snow pack, impervious surface and hydrological runoff. US census data, land ownership, roads and urban land areas were used to map home density classes across the US. The resulting home density classes were used as a basis of mapping ecological connectivity as a function of naturalness. Loss of natural ecosystems was estimated as a function of land use intensification. These and other indicators produced by this project allow for assessment of park condition well beyond what was previously possible.

In addition to the indicators that were produced for all the parks in the project, cooperators appreciated that we also developed indicators of interest to individual networks based on ecological conditions in their parks and management issues. For example, urban development, impervious surface, and effects on stream biota where high priorities in the Eastern Rivers and Mountain Networks and indicators of these factors were developed for them. Similarly, the Greater Yellowstone Network was especially interested in phenology of grasslands as related to ungulate forage production and we developed indicators specifically for them. More emphasis was placed on forecasting snow pack and runoff for the Sierra Network because of their concern about climate change impacts on water resources. The differential ranking of relevance of the indicators (Question 3) reflects the networks differing ecological conditions and management issues.

The concept of delineating a protected area centered ecosystem was seen as highly valuable. Park staff have long been aware of actual or potential interactions between national parks and surrounding lands. However, an objective, ecologically based framework for identifying key surrounding lands and processes was not available. Our method was designed to provide for objective delineation of protected area centered ecosystems. These ecosystem boundaries identify the spatial domain for monitoring and assessment around parks. They provide a context for prioritizing research to better understand cross boundary impacts on parks. They also provide a logical construct for developing cooperative conservation initiatives (e.g., conservation easements) on surrounding lands to maintain park condition and function. Collaborators embraced the PACE approach, describing how it helped them to think at larger spatial scales about factors outside of parks that may influence park conditions.

Objective 2. Adding value through analysis and forecasting. The project sought to add two dimensions to the existing NPS I&M monitoring program. These were producing the indicators for several time periods to depict trajectories of change. This was done through hindcasting and forecasting using historic data sets and simulation models. The second dimension was adding value to the resulting data through analysis and synthesis and "telling stories" about the major changes in ecological conditions in and around the parks (see summary reports for each network). The cooperators embraced these approaches, with specific analyses being of high interest in each network. Projection of urban expansion under alternate future scenarios and impacts on stream biota and terrestrial connectivity are being used in the Eastern Rivers and Mountains for management planning. Change in key ecosystem types past to present lead the Greater Yellowstone Network to initiate additional research on the steppe sagebrush ecosystem type because of relatively high loss rates largely on private lands outside of parks. In the Sierra Network, projections of climate change effects on snowpack and hydrology are of high interest and may influence fire management policies. The cooperators suggested that adding value to monitoring data through analysis and forecasting will likely be essential in the NPS I&M Program in the future.

Objective 3. Deliver these products and a means to integrate them into the NPS I&M decision support framework. The project delivered a full suite of decision support products. These include geospatial data for all indicators, methods for updating the indicators (standard operating procedures), supporting publications, an internet interface for displaying the data, summaries of change in ecological condition parks in each of the four networks, and resource briefs on major indicators for park managers. These products where developed with substantial input from cooperators and the cooperators expressed satisfaction with the final versions.

Goal. Expectations were less well met with regards to the goal of integrating our indicators into NPS I&M decision support and enhancing natural resource management within and surrounding national parks. The project made various contributions to decision support. The approach and structure of our project positively influenced the development of NPS NPScape project within the national NPS I&M office. NPScape uses existing data sources to monitor change in human demography and land use across the I&M networks. Our approach for delineating protected area centered ecosystems has been incorporated into the Sierra's networks natural resource assessment, is being considered for use for all parks by the NPScape program and by the Great Northern Landscape Conservation Cooperative. Our hindcasts and forecasts are being used by the networks for prioritizing research and scenario planning. For example, our modeling of land use change in the Eastern Rivers and Mountain networks is being used to plan corridors to maintain park connectivity under future development. Results of climate and land use change in the Greater Yellowstone network contributed to the interagency science agenda for the region (Tom Olliff pers. comm.). Finally, the project has helped NPS I&M staff to better understand some of our more complex indicators (like primary productivity) and elucidate to decision makers their relevance to management. The expectation that NPS I&M networks would incorporate production of our indicators into their monitoring protocols has largely not yet occurred, however. The translation of the results of the project to NPS decision makers has also been limited. Initial reception of our products by NPS has been positive, but the 3-year duration of the project is not long enough to accommodate the ongoing process of review, evaluation, understanding, and incorporation of the results.

Specific Contributions of the Project to NPS

- Delivery of some 16 indicators of landscape condition that are largely highly relevant and novel to the NPS I&M Program and to the case study national parks.
- Written methodologies for producing the indicators in the form of NPS Standard Operating Proceedures and background peer=reviewed publications.
- Written summaries of the major trends in landscape condition of the case study parks and implications for management.
- Methods for delineating the lands surrounding national parks that are most relevant to maintaining park condition under land use change as a basis for monitoring, research, and collaborative management.
- Hindcasts and forecasts of park condition that provide a unique temporal context to inform management decision making.
- Means by which the NPS can obtain data on the lands surrounding parks that cannot be obtained by traditional field methods due to ownership and privacy issues.
- Exposure of NPS collaborators to 21st century cutting-edge environmental monitoring, analysis, and modeling that can help to manage and protect parks better.
- An approach for hindcasting, forecasting, analyzing, and delivering to users complex indicators of landscape condition that can serve as a model for other applications.
- Resource briefs on major trends in park condition that the NPS can use to communicate with stakeholders and the public.

Factors Contributing to Success

1. NASA Applied Sciences Program and the NPS I&M Program provided substantial resources to allow a sustained effort to achieve project objectives.
2. Participation of the NPS I&M Landscape Ecologist as a P.I. on the project helped adapt the project to NPS I&M needs and culture and increased the credibility of the project to the NPS I&M personnel. The commitment of ca 20% of his time to the project greatly enabled success on these fronts.
3. NPS I&M network and park staff showed a high level of commitment to the project and provided feedback which helped the project stay on track.
3. The NASA data and products delivered are highly relevant to monitoring park condition and were largely not previously available to the NPS.
4. The project P.I.s had a history of successful collaboration with staff in each I&M network and park prior to the project, thus a high level of trust was in place from the beginning.
5. The P.I.s and collaborators had sustained contact throughout the project including face to face meetings at workshops and field trips, and repeated internet-based seminars.
6. The project adapted the approaches and terminology from the NPS I&M Program (e.g., indicators, standard operating procedures, resource briefs.

Factors Inhibiting Success

Limited Resources of NPS I&M Networks. Respondents to the questionnaire mentioned repeatedly that limits on staff time hindered their ability to invest more deeply in this project, to adapt our indicators into their monitoring protocols, and to share project results with environmental decision makers in the NPS. Their time is largely already allocated to the monitoring of indicators that where selected before this project was initiated and to other activities. While the project produced data sets and methods for updating them, it is difficult for these to become integral parts of NPS I&M decision support if I&M staff do not have adequate time to review, use, and become familiar them.

Complexity of Some Indicators. Indicators such as primary productivity are difficult to measure on the ground and are primarily estimated through integration of remotely sensed data, data from in situ networks (e.g. met stations), and simulation models. While our I&M collaborators increasingly came to understand how these were generated and their relevance to management, they indicated that they are less likely to adapt an indicator that they cannot produce in house and that it is more challenging to communicate the importance of to park managers the importance of indicators. Difficulty in field validating complex indicators and unknown levels of certainty in the results also impede adaptation of indicators. Finally, experience in remote sensing and simulation modeling are not widespread in the NPS I&M, which further impedes adaptation.

Timing of Delivery of Indicators. Due to their complexity, the development of some indicators required ca 2.5 years of the 3 year project. Hence, the collaborators had relatively little time to review methods and evaluate spatial patterns and trends over time in the indicators.

Turnover in NPS I&M staff. We originally anticipated training individual I&M staff in the development and analysis of the indicators. When we experienced an unexpectedly high rate of turnover of I&M staff, we put more emphasis on preparing written methods that could be used by future I&M staff. A disadvantage of this approach is that collaborators indicated that they are less likely to use methods that they have not helped to develop nor received training in. An advantage of this strategy is that Networks that did not directly participate in the project have much better access to the methods we developed.

Lessons Learned

Many remote sensing-based monitoring projects, especially those that involve many sites and collaborators, will likely face challenges similar to those we experienced. Some of these are common to most large problems, while others are more specific to working with complex technologies and management agencies like NPS. Here, we summarize a few important lessons, emphasizing things that worked well for us.

Allocate sufficient time to develop a genuine science-management partnership

To effect a genuine collaboration between scientists, resource specialists, and managers takes more time, potentially much more time, to design, develop, implement, conduct, communicate, report, and deliver products than is typical for research projects. Remote-sensing projects tend to involve complex technology, sophisticated methods, and sometimes obscure measurements. ‘Black box’ calculations that managers don’t understand are unlikely to sway opinion or usefully contribute to important decisions unless they are skillfully explained by scientists. Time is required to develop a common language and explain how results were obtained and what they mean.

The transition of methods and results from research to operations requires a long-term commitment from all parties (>3 years). Efforts to apply research data products for operational decision support often discover that more research is needed. Methods that apply at one site may not work well elsewhere, or it may be necessary to develop additional ecological or physical relationships to convert results of spectral analysis into units that are meaningful to managers. There is rarely a finite hand-off or delivery of research results accompanied by a seamlessly integration into a management decision support framework. In most cases, only through the long-term development of scientific understanding and collaboration with managers will decision making be positively influenced by research results.

Communicate results in a management-relevant context

Uptake of results occurs most readily when they are available to the right people, at the right time, and in the right format. In parks, budget exercises, annual work plan, and field activities are typically conducted at the same time each year. Monitoring data need to be available when results can feed into decisions. Express results using formats and language that is familiar to managers and make connections between results and attributes that affect decisions. For example, it may be possible to correlate soil moisture and plant stress (as estimated from a simulation model driven by MODIS products) into a coarse measure of fire risk. Patterns of soil moisture may be of little interest to managers, but fire risk is almost always of great interest. Critical evaluation by end users will likely be required to ensure that the data products for decision support are available at the appropriate spatial and temporal scales.

Conform or embellish existing frameworks and processes

For PALMS, this included using the existing I&M Network and Program structure as a primary means to communicate across parks and project staff. We built on exiting guidelines and formats for publications, method documents, and fact sheets, and we linked our efforts to specific personnel and positions within I&M. NPS collaborators were familiar with these products, and we minimized the costs associated with designing these products. We largely followed existing practices and produced reports and results for specific audiences.

Plan for persistence and change

NPS I&M is charged with conducting long-term monitoring. Protocols or products that do not persist through time will not meet Program goals. The PALMS team’s strategy to produce versioned SOPs was very well aligned with I&M protocol development needs. Production of detailed methods ensures persistence of standard methodology, and versioning provides a clear means to update individual procedures or an entire protocol with changes in technology or understanding.

Build on existing, widely used data analysis tools and software frameworks, even if they seem inefficient

The use of existing tools and frameworks permits rapid development and reduces development costs. It increases client "buy-in" because the efficacy of application components is known, and it ensures usability. If possible, exchange personnel to gain cross-enterprise experience in the tools and day-to-day processes used for data management and decision making. NPS and the NASA-Ames groups employed software development teams with complementary skills; each group was familiar with the technologies, programming languages, and infrastructure that they could support after the initial development project ended. Communication between the groups was important to identify technologies that would most likely be adopted.

Practice rigorous scope control to maximize the chance of success

Operational use of remotely sensed data and technology requires robust, repeatable, credible, and defensible methods. Through discussion with collaborators, we continually refined the scope of work and avoided 'mission creep' by focusing on specific functions, variables, and reporting products.

Nurture Relationships with Individual Collaborators

In decentralized agencies like the NPS, individuals strongly influence local activities and priorities. The success of our project benefited greatly from the sustained interest and participation of a few individual within each network. These individuals were primarily network coordinators and network ecologists that primarily do integrated and synthetic work. These individuals helped us shape the project to be most relevant to the NPS and helped us communicate its value to colleagues. We were less forthright in sustaining relationships with the data managers and spatial analysists that have the technical skills to execute our resulting methods. Doing so would probably have increased the likelihood of adoption of our indicators by I&M, notwithstanding the time limitations described above.

Conclusions and Recommendations

The PALMS framework, approach, and methods were developed specifically to meet the needs of NPS I&M, but the resources and impacts the indicators address are common to protected areas worldwide. Very few North American parks – and probably no NPS units – are sufficiently remote and large enough to sustain the biodiversity once native to the park, or to be unaffected by activities outside park boundaries (GAO 1994; Carroll et al. 2004). Human development is increasing more rapidly near the boundaries of protected areas than elsewhere in the U.S. (Radeloff et al. 2010) and other continents (Wittemyer et al. 2008). Furthermore, climate changes are projected to result in huge shifts in ranges of species and habitats (Iverson et al. 2008; Belant et al. 2010; Cole 2010; Gonzalez et al. 2010). These threats emphasize the need for integrated assessments of the condition of landscapes around protected areas at a range of spatial scales.

PALMS is unusual among monitoring projects for the breadth of attributes addressed by the suite of indicators, and the use of various models to assimilate data. The suite of indicators developed by PALMS can provide a rich picture of landscape context and the condition of attributes that conserve or threaten biodiversity in and around parks. Other reviews have illustrated the value of remotely sensed data to monitor traits not addressed by PALMS, but also important to supporting biodiversity (Turner et al. 2003; Bergen et al. 2009) and the broader goals of protected area monitoring (Kerr and Ostrovsky 2003; Gross et al. 2006; Gross et al. 2009). The potential to increase the use remote sensing for operational monitoring is great, especially when the value of remotely sensed data is enhanced through multi-factor analyses and modeling

NASA data and products are highly relevant to the NPS Inventory and Monitoring Program. This was clearly illustrated in the responses of our NPS collaborators to the project assessments and the success of other remote-sensing based NPS applications (e.g., the work of Robert Kennedy at Oregon State University, and Jeff Morisette and Brad Reed of USGS). Indicators relating to phenology of vegetation, ecosystem productivity, run-off, connectivity, and biodiversity are very informative for monitoring change in park condition under land use and climate change and useful as a context for management. Our methods allow these indicators to be collected not only inside of park boundaries, but also outside of parks where field collection is often difficult or impossible. The methods also allow the NPS to track changes at spatial scales larger than parks, which are critical to maintaining ecological dynamics within parks. Interest in these indicators and methods will likely increase as the NPS develops and implements its climate change adaptation strategy.

This partnership between NASA and the NPS has been very successful. It has helped the NPS understand and appreciate the value of these sometimes complex indicators of ecosystem condition and helped to lay the foundation for their integration into the NPS I&M Program. It will take more time and effort to fully achieve the original goal, "Integrate the routine acquisition and analysis of NASA Earth System Science products and other data sources into the NPS I&M DSTs and use these NASA products to evaluate and forecast ecological condition of US National Parks, thereby enhancing natural resource management within and surrounding national parks". Facilitating the production and use of complex NASA data and products by the numerous people and NPS units involved in the NPS I&M program will require sustained commitment over several years.

We recommend the following as the next steps in moving towards this goal.
1. Where practical, integrate the indicators and methods developed in this project into the NPS I&M NPScape effort. Coordination through a national office will best facilitate the use of these indicators by the 32 I&M networks. Whereas only a subset of the indicators would be produced by the NPScape office, it would coordinate the production, analysis, and distribution of all the results. Candidate indicators for NPScape to consider include: ecosystem type composition, impervious cover change, housing density class, landscape connectivity, and pattern of natural landscapes, land use, greater protected area ecosystem boundaries.

2. Continued support from NASA is likely required to provide the indicators that are derived from complex ecosystem models. These include the weather and climate, extreme disturbance events, and primary productivity indicators produced by TOPs and the future land cover and use indicators produced by the Woods Hole Research Center. The NPS I&M Program does not have the expertise, hardware and software to assume production of these products. TOPS is currently moving towards producing these indicators for the continental US. We recommend TOPS provide direct access to model outputs via e.g. an ArcGIS Server, OPeNDAP server, or other mechanisms that permits automated, internet-based use by the NPS and others, and direct retrieval from ArcGIS clients, the most commonly used geospatial analysis software within NPS.

3. Use NASA and NPS I&M education funds to sponsor training sessions during 2011 for the networks collaborating in this project and other interested networks on the use of the indicators and methods produced in this project. As requested by the collaborators, this would allow a critical final phase of the project to transfer the technology to the networks. This would likely lead to the networks adopting some of the indicators into their programs.

4. NPS I&M collaborators are requested to "champion" the integration of products from this project into NPS I&M decision support. Incorporation of new products into NPS decision-making is an ongoing process and requires considerable time and effort. Resource limitations, "institutional inertia", and other factors can be overcome only by continuing promote and use approaches and products from the project until they become integrated into the NPS I&M Program. The collaborators of this project are now substantially invested in the project and are in the best position in the NPS to ensure high long-term contributions from the project.

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Appendix 1. Products Resulting from this Project.

The following documents can be found at: http://science.nature.nps.gov/im/monitor/lulc/palms/.

Key documents

PALMS Fact Sheet, 2008.
NASA Project Proposal, 2005.
PALMS Assessment Report, 2009.
PALMS Indicator Summary table March 2009

Procedures and Standard Operating Procedures (SOPs)

Goetz, S.J. and G. Fiske. 2009. PALMS SOP – GIS Methodology for mapping Biotic Integrity and Indicator Taxa across watersheds in the eastern USA. National Park Service, Fort Collins, CO.

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Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS SOP - Analyzing Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. (3.3 MB)

Piekielek, N.B., C. Davis and A. Hansen 2010. PALMS SOP - Estimating Protected-area Centered Ecosystems. Inventory and Monitoring Program, Natural Resource Program Center, National Park Service, Fort Collins, CO. (10 MB)

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Tools and Data

Ecosystem type and change Arc tools

Protected-area centered ecosystems (PACE) Arc tools

PACE example results xls sheets

The PACE geospatial data set

Summary Reports for each Collaborating Network

Landscape Conditions and Trends in and around Yellowstone and Grand Teton National Parks.

Landscape Conditions and Trends in and around Delaware Water Gap and Upper Delaware National Recreation Areas

Landscape Conditions and Trends in and around Rocky Mountain National Park

Landscape Conditions and Trends in and around Yosemite and Sequoia-Kings Canyon National Parks

Most Relevant Publications

Goetz, S.J. and G. Fiske. 2008. Linking the diversity and abundance of stream biota to landscapes in the Mid-Atlantic USA. Remote Sensing of Environment 112:4075-4085.

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Resource Briefs

Eastern Rivers and Mountains Network
- Aquatic Macroinvertebrates
- Impervious Cover
- Surface Water

Greater Yellowstone Network
- Land Use Change
- Ecosystem Type Change

Rocky Mountain Network

Sierra Network

TOPS Data and Display via Ecocast

Data and display for each of the indicators produced by TOPs for each of the collaboratoring Networks can be found at: http://ecocast.arc.nasa.gov/dgw/dboard/XXXX. ROMO, YELL, SIEN, DEWA